Available online at www.sciencedirect.com

ScienceDirect

Procedia Manufacturing 2 (2015) 392 – 396

Procedia MANUFACTURING

2nd International Materials, Industrial, and Manufacturing Engineering Conference, MIMEC2015, 4-6 February 2015, Bali Indonesia

Electrical and Reliability Performance of Molded Leadless Package for High-Voltage Application

A. Suhaimi[a,]*, M. T. Asmah[b]

[a]ON Semiconductor Malaysia Sdn. Bhd., Lot 122, Senawang Industrial Estate, Seremban 70450, Malaysia
[b]Faculty of Electrical and Electronic Engineering, Universiti Tun Hussein Onn Malaysia (UTHM), Batu Pahat 86400, Malaysia

Abstract

This paper investigates the influence on electrical and reliability performance of molded leadless package for high-voltage power integrated circuit application. Semiconductor devices are mostly encapsulated by using epoxy molding compounds which act as protection for the ICs from damage to the harsh environment. Quad Flat No Lead was selected since the application requirement for compact AC to DC portable adapter charger and more input and output pin. High-voltage package was designed based on the IPC-2221 standard specification and creepage distance was calculated under external component lead, uncoated. Two epoxy molding compounds were used namely as type A and B. Key properties of EMCs were identified such as ionic content, glass transition temperature and volume resistivity. The electrical tested at room temperature on high-voltage leakage current at 700 V showed EMC B has no failure compared with EMC A. On top of that, electrical parametric distribution showed that the Cpk of EMC B was extremely robust compared with EMC A. Reliability test was conducted for high temperature operating life test at 115˚C and EMC B was passed up to 1000 hours while EMC A was failed. Meanwhile, High Temperature Storage Life test at 150˚C and Temperature Humidity Bias Test at condition 85˚C, 85% relative humidity showed that EMC B was passed for 1000 hours but EMC A was failed at 168 hours. However, both compounds A and B were passed delamination criteria tested by scanning acoustic tomography technique before and after subjected to moisture sensitivity level 1.

Keywords: Epoxy molding compound ; Molded leadless package ; High voltage ; Reliability

* Corresponding author. Tel.: +6-06-682-1130; fax: +6-06-678-2262.
E-mail address: Suhaimi.Azizan@onsemi.com

doi:10.1016/j.promfg.2015.07.069

1. Introduction

High-voltage device has been widely used in many applications such as in telecommunication, power supply, home appliances, electro-optic and many more [1,2,3,4]. Mobile phone adapter charger is one of the example possesses regulator integrated circuit (IC) and requires to be operated at high-voltage (HV) mode. Epoxy molding compound (EMC) is a compound that has been used to encapsulate plastic semiconductor packages [5] before this semiconductor device is releases as a final product. EMC contains anionic halogens such as chloride ions from epichlorohydrin compound that used for resin epoxidation while bromide ions is incorporated into this resin as a flame retardant to the molding compound [5,6]. In addition, EMC also contains cations for instance potassium (K^{+}), sodium (Na^{+}) and antimony (Sb^{+3}) which also act as flame retardant for molding compound [6,7]. However, the presence of these flame retardant elements in a high concentration in the molding compound will contribute to leakage current problem of IC device [6]. Furthermore, an increase in device current will reduce the volume resistivity (VR) value and cause failure during electrical testing. However, this VR value is one of the important property for EMC. Low and high volume resistivity is classified as magnitude of 10^{11} and 10^{13}, respectively, during the electrical testing [8]. The other key property for epoxy molding compound is glass transition temperature (T_g). Increasing in T_g value will help to improve cross-linking between polymer compound and prevent the anions and cations transportation in the EMC. Therefore, higher T_g value leads to increase the high voltage device performance [6]. However, leakage current will occur when higher voltage than T_g value was applied to the device which cause anions and cations to transport easily [9].

2. Experimental

The molded leadless package was designed using AutoCAD software LT version. The design rule was followed the Institute for Interconnecting and Packaging Electronic Circuit (IPC-2221) standard. The creepage distance was calculated based on A6, external component lead/termination, uncoated and minimum creepage gap is shown in Table 1. A5 is refer to external conductor, with conformal coating over assembly (any elevation) while A7 is refer to external component lead termination, with conformal coating (any elevation). Since the device input at high line was approximately 400 volts dc, hence the minimum creepage distance can be expressed by equation (1) [10].

$$\text{Minimum spacing (A6)} = 0.00305 \text{ mm x } 400 \text{ volts} = 1.22 \text{ mm} \tag{1}$$

Table 1. Minimum creepage spacing based on IPC-2221 standard.

Voltage between conductors (DC or AC peaks)	Minimum spacing		
	Assembly		
	A5	A6	A7
0-15	0.13 mm	0.13 mm	0.13 mm
16-30	0.13 mm	0.25 mm	0.13 mm
31-50	0.13 mm	0.4 mm	0.13 mm
51-100	0.13 mm	0.5 mm	0.13 mm
101-150	0.4 mm	0.8 mm	0.4 mm
151-170	0.4 mm	0.8 mm	0.4 mm
171-250	0.4 mm	0.8 mm	0.4 mm
251-300	0.4 mm	0.8 mm	0.8 mm
301-500	0.8 mm	1.5 mm	0.8 mm
> 500	0.00305 mm /volt	0.00305 mm /volt	0.00305 mm /volt

In this study, two types of EMC were used i.e. type A and type B. Key element properties of EMC which are ionic content, glass transition temperature, T_g and volume resistivity, VR were studied in this project. The properties for both EMC A and B are shown in Table 2. The package was molded with 2 EMCs using the same equipment, molding parameter and time until singulated process. The final electrical test (FT) was conducted by Eagle tester system (ETS 364) and Ismeca handler incorporated with high-voltage load board. Tester was placed at room temperature environment and high-voltage leakage current at 700 volts (I_{HV-700}) was measured. All samples were submitted for reliability by went through preconditioning moisture sensitivity level 1 (JESD22-A113F). Package delamination was measured before and after preconditioning using Scanning Acoustic Tomography (SAT). The reliability test was performed based on High Temperature Operating Life (HTOL), High Temperature Storage Life (HTSL) and Temperature Humidity Bias Test (THBT). The temperature for these three tests was set to 115˚C, 150˚C and 85˚C, respectively. The relative humidity (RH) for THBT was set to 85%. The passing criteria for all reliability tests were 1000 hours.

Table 2. Properties of EMC type A and B.

Property	EMC type	
	A	B
Chloride content Cl^-(ppm)	20	13.5
Sodium content Na^+(ppm)	3	2.2
Glass Transition Temperature, T_g (˚C)	121	166
Volume resistivity (ohm.cm) @ RT	1^{16}	1^{15}
Volume resistivity (ohm.cm) @ 150˚C	5^{12}	1^{12}
Adhesion promoter	Yes	Yes

3. Result and discussion

High-voltage package was designed with minimum metal to metal spacing 1.22 mm to avoid creepage between HV and LV pin as shown in Fig. 1. (a). High-voltage pin was denoted as HV while Low-voltage pin was assigned as LV. The gold wire was used as interconnect between die and leadframe and the using scanning electron microscope (SEM) image of bonded device is exhibited in Fig. 1. (b).

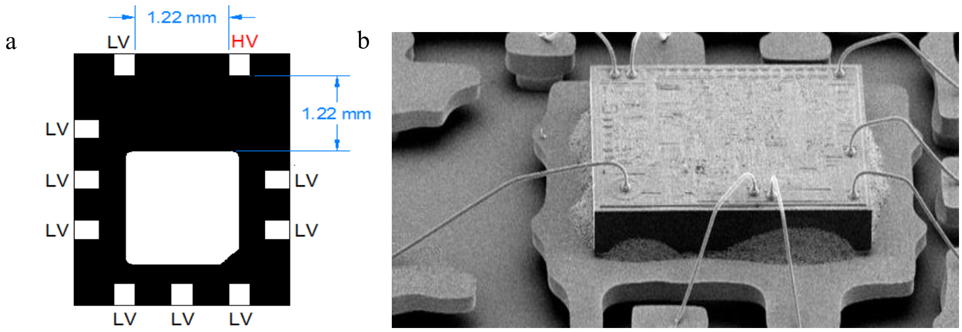

Fig. 1. (a) Bottom view of HV package outline; (b) SEM image of bonded device

No failure was observed for EMC B during final electrical test for high-voltage leakage current (I_{HV-700}). However, EMC A resulted 45% yield loss during FT. Based on the test distribution analysis, the IHV test Cpk was more than 3.5 for EMC B while less than 0.2 for EMC A. The distribution result for EMC A and EMC B is shown in Fig. 2. (a) and Fig. 2. (b), respectively.

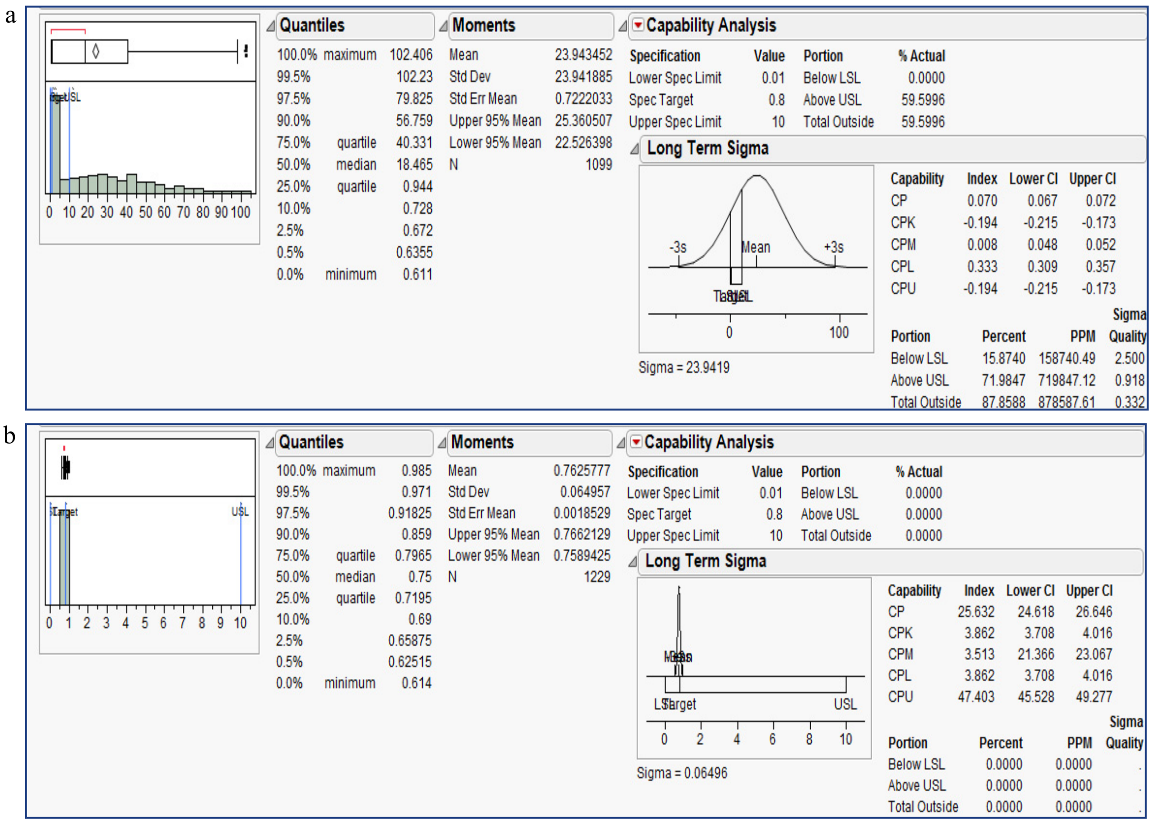

Fig. 2. Electrical distribution of EMC (a) type A; (b) type B.

Table 3. Summary of the reliability results.

EMC type	A			B		
Duration	168 hours	500 hours	1000 hours	168 hours	500 hours	1000 hours
HTOL	failed	NA	NA	passed	passed	passed
HTSL	failed	NA	NA	passed	passed	passed
THBT	failed	NA	NA	passed	passed	passed

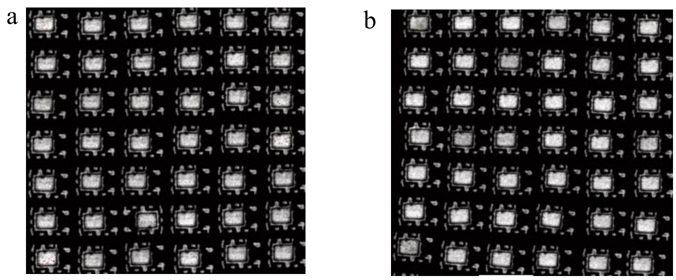

Fig. 3. Scanning acoustic tomography image after MSL 1 (a) EMC A; (b) EMC B.

In this study, the reliability tests were performed at three different hours and the summary of the reliability result is denoted in Table 3. The reliability test result showed that EMC A was failed at 168 hours for all three reliability tests. Therefore, no further reliability tests were conducted and this compound was not compatible for high voltage application. Meanwhile, reliability test result showed that EMC B was passed until 1000 hours for all reliability tests. Therefore, this compound was compatible for high voltage application compared with EMC A. In addition, no package delamination was observed for both EMC A and B during moisture sensitivity level 1 test and the SAT result is shown in Fig. 3. (a) and Fig. 3. (b) for EMC A and EMC B, respectively.

One of the EMC property is high ionic content and this property contributes to the leakage failure. This property is expressed from the ionic concentration in the properties table (Table 2) and from the electrical (Fig. 2) and reliability results (Table 3). When high-voltage was apply to the molding compound, the ionic element transportation will strongly increase and cause an accumulation of charge at the passivation and EMC layer interface [9]. Furthermore, the device leakage current may also contributed by the possibility of ion migration path through the passivation layer of the compound [11]. Therefore, lower ionic content in EMC is necessary to ensure a good performance of the device. In addition, T_g parameter became one of the contributor to the leakage failure for the electrical and reliability test. From this study, higher T_g will help to increase the polymer cross-linking in the EMC and restrict the ions from freely move [6] thus help to avoid leakage failure. However, when the applied voltage was applied above T_g value, the leakage current will occur because the ions in the compound will easily transport throughout the compound [9]. The result for volume resistivity shows no significant effect of this property to the leakage current in the range of magnitude 1^{15} to 1^{16} (at room temperature) and 1^{12} (at 150 ˚C). In addition, no package delamination was observed in this study because of the adhesion promoter was added into the epoxy molding compound as denoted in Table 2.

4. Conclusion

High-voltage integrated circuit package was successfully designed and followed the IPC-2221 standard guideline. Ionics concentration and T_g became the important properties for EMC that contribute to the leakage current during high-voltage operation mode. Lower ionic concentration and higher T_g help to overcome the leakage failure while no significant influence of VR to the leakage current was observed. An addition of adhesion promoter helps to prevent package delamination from occur.

Acknowledgements

The author would like to express gratitude to ON Semiconductor Malaysia materials, facilities and financial support. The author would like to thank to Dr. Asmah Mat Taib, UTHM for her precious suggestion and advice.

References

[1] Y.J. Park, S.C. Lyu, T.S. You, Development of High Density High Voltage Power Supply for Phased Array Transmitters, Pulse Power Conference IEEE, Monterey, CA, 2005, pp. 182-185.
[2] D.Disney, Z.J. Shen, Review of Silicon Power Semiconductor Technologies for Power Supply on Chip and Power Supply in Package Application, Power Electronics IEEE, San Jose CA, 2013, pp. 4168-4181.
[3] L.Katzir, D. Shmilovitz, Compact Multi-Level High-Voltage Power Supply for Vacuum Application, Vacuum Electronics Conference IEEE, Monterey CA, 2014, pp. 457-458.
[4] A. R. Tamuri, N. Bidin & Y. M. Daud, High Voltage Power Supply for Electro-Optics Application, IJRRAS 3(2), 2010, pp. 143-147.
[5] L. Lantz, M.G. Pecht, Ion Transport in Encapsulants used in Microcircuit Packaging, Components and Packaging Technologies, IEEE, 2003, pp. 199-205.
[6] M.A. Alam, D. Das, M.H. Azarin, M.G. Pecht, Influence of Molding Compound on Leakage Current in MOS Transistors, Components and Packaging Technologies, IEEE, 2011, pp. 1054-1063.
[7] L. Lantz, S. Hwang, M. Pecht, Characterization of Plastic Encapsulant Materials as a Baseline for Quality Assessment and Reliability Testing, Microelectron, 2002, pp. 1163-1170.
[8] M. Van Soestbergen, R.T.H Rongen, J. Knol, A. Mavinkurve, J.H. Egbers, S. Nath, G.Q. Zhang, L.J. Ernst, Electrical Characterization of Plastic Encapsulations using an Alternative Gate Leakage Test Method, Reliability Physics Symposium, Phoenix AZ, 2008, pp. 462-467.
[9] P.M. Biesheuvel, M. Van Soestbergen, A. Mavinkurve, L.J. Ernst, G.Q. Zhang, Ionic Polarisation Layers in Polymer Electrolyte, Thermal, Mechanical and Multi-Physic Simulation and Experiments in Microelectronics and Microsystem, Freiburg im Breisgau, 2008, pp. 1-5.
[10] L. Jiyuan, Analysis and Experimental Study of the Package Stress in a QFN Plastic-Encapsulated Package, IEEE Transactions on Components Packaging and Manufacturing Technology, 2014, pp. 1303-1308.
[11] C. Hong, B. Henson, T. Scelsi, R. Hance, An Accelerated Sodium Resistance Test for IC Passivation Films, IEEE, Las Vegas, NV, 1995, pp. 318-325.